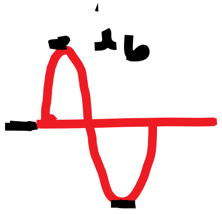
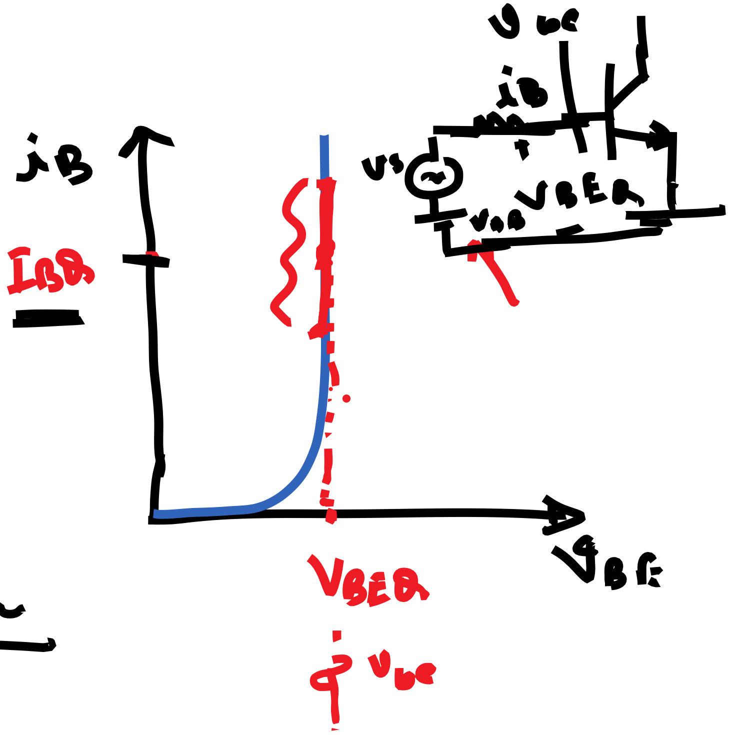
BJT Amplifiers

$i_C = I_S \exp\left(\frac{v_{BE}}{V_T}\right)$

* Small Signal: ??

$i_B = \frac{I_S}{\beta} \exp\left(\frac{v_{BE}}{V_T}\right)$; $v_{BE} = V_{BEQ} + v_{be}$





$i_B = \frac{I_S}{\beta} \exp\left(\frac{V_{BEQ} + v_{be}}{V_T}\right) = \frac{I_S}{\beta} \exp\left(\frac{V_{BEQ}}{V_T}\right) \cdot \exp\left(\frac{v_{be}}{V_T}\right)$

$i_B = I_{BQ} \cdot \exp\left(\frac{v_{be}}{V_T}\right)$; $\boxed{v_{be} \ll V_T}$ ← Relation

$\frac{v_{be}}{V_T} \ll 1$

$\cancel{I_{BQ}} + i_b = \cancel{I_{BQ}} \cdot \left[1 + \frac{v_{be}}{V_T}\right]$

$\Rightarrow i_b = \frac{I_{BQ}}{V_T} \cdot v_{be}$; $i_b \propto v_{be}$ "linear relation"

$V_T \cong 26$ mV at 300K

Rule of Thumb "$v_{be} < 10$ mV" ←

BJT Amplifiers

Harmonic Distortion:

$$e^x = 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \cdots$$

$v_{be} = V_m \sin\omega t \; ; \; v_{be} \ll V_T$

$$\exp\left(\frac{v_{be}}{V_T}\right) = \exp\left(\frac{V_m \sin\omega t}{V_T}\right) = 1 + \frac{V_m \sin\omega t}{V_T} + \frac{V_m^2 \sin^2\omega t}{2V_T^2} + \frac{V_m^3 \sin^3\omega t}{6V_T^3}$$

$$\sin^2\omega t = \frac{1}{2}[1 - \cos 2\omega t] = \frac{1}{2}[1 + \sin(2\omega t + 90°)]$$

$$\sin^3\omega t = \frac{1}{4}[3\sin\omega t - \sin 3\omega t]$$

$$\exp\left(\frac{v_{be}}{V_T}\right) = \underbrace{\left[1 + \frac{1}{4}\left(\frac{V_m}{V_T}\right)^2\right]}_{V_0 \text{ DC}} + \underbrace{\frac{V_m}{V_T}\left[1 + \frac{1}{8}\left(\frac{V_m}{V_T}\right)^2\right]\sin\omega t}_{V_1} \underbrace{- \frac{1}{4}\left(\frac{V_m}{V_T}\right)^2 \sin(2\omega t + 90)}_{V_2}$$

$$\underbrace{- \frac{1}{24}\left(\frac{V_m}{V_T}\right)^3 \sin 3\omega t}_{V_3}$$

i_b

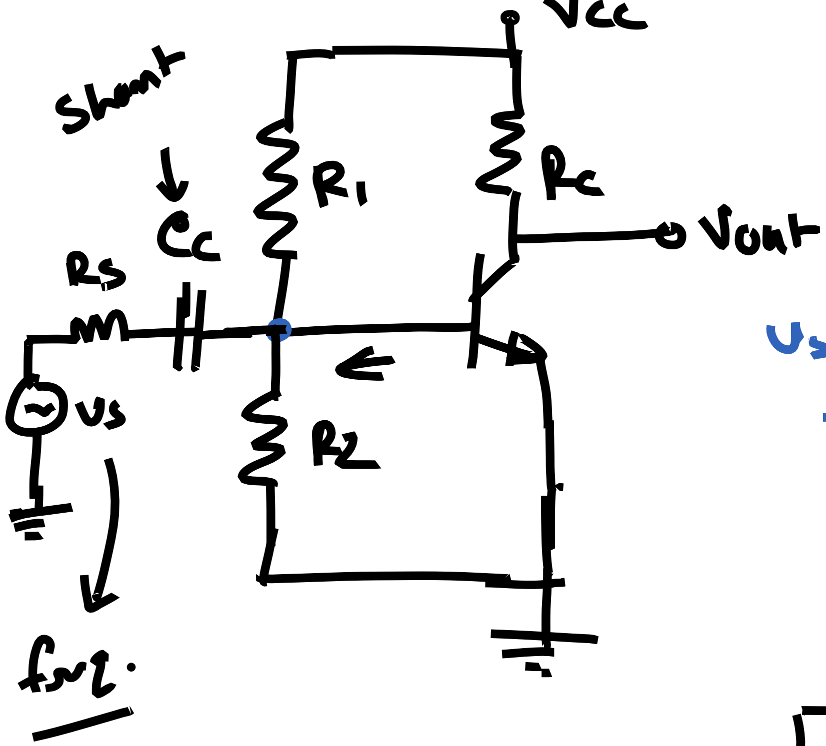
Figure of merit

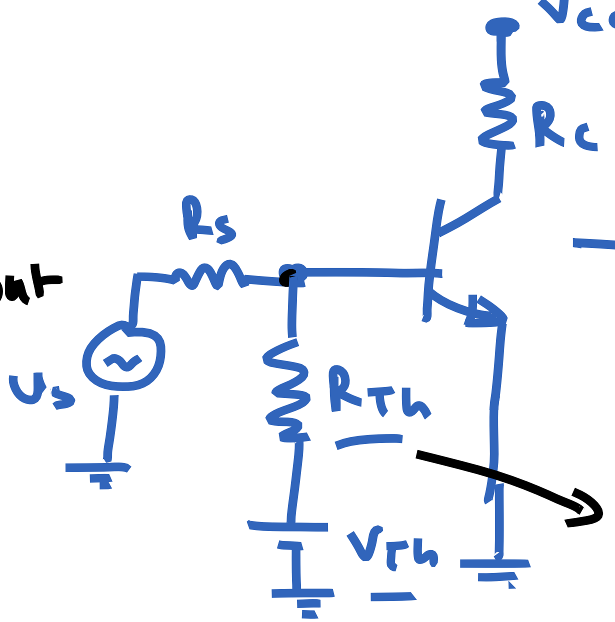
Total Harmonic Distortion (THD) $= \frac{\sqrt{V_2 + V_3 + \cdots}}{V_1} \times 100\%$

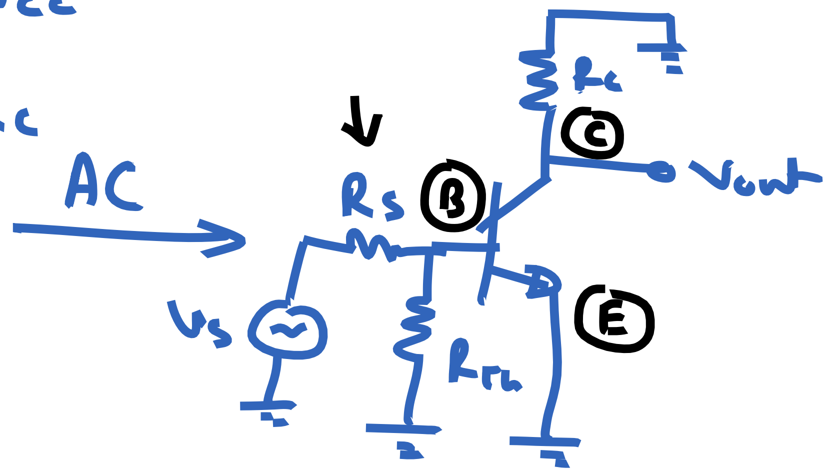
$\boxed{THD < 10\%}$

BJT Amplifiers

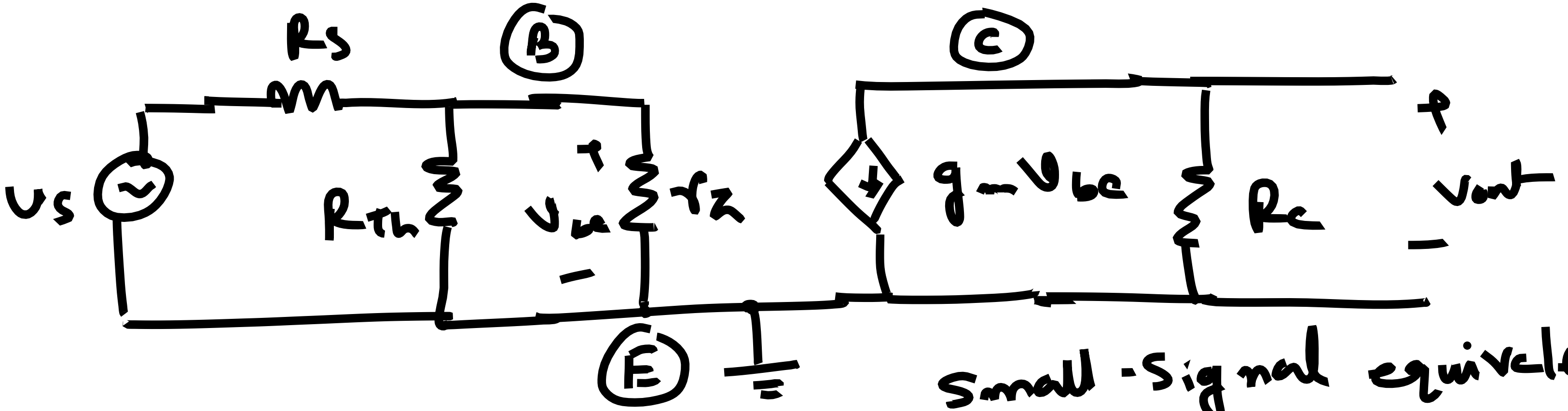
Common Emitter (CE) Amplifier circuit with voltage divider biasing:





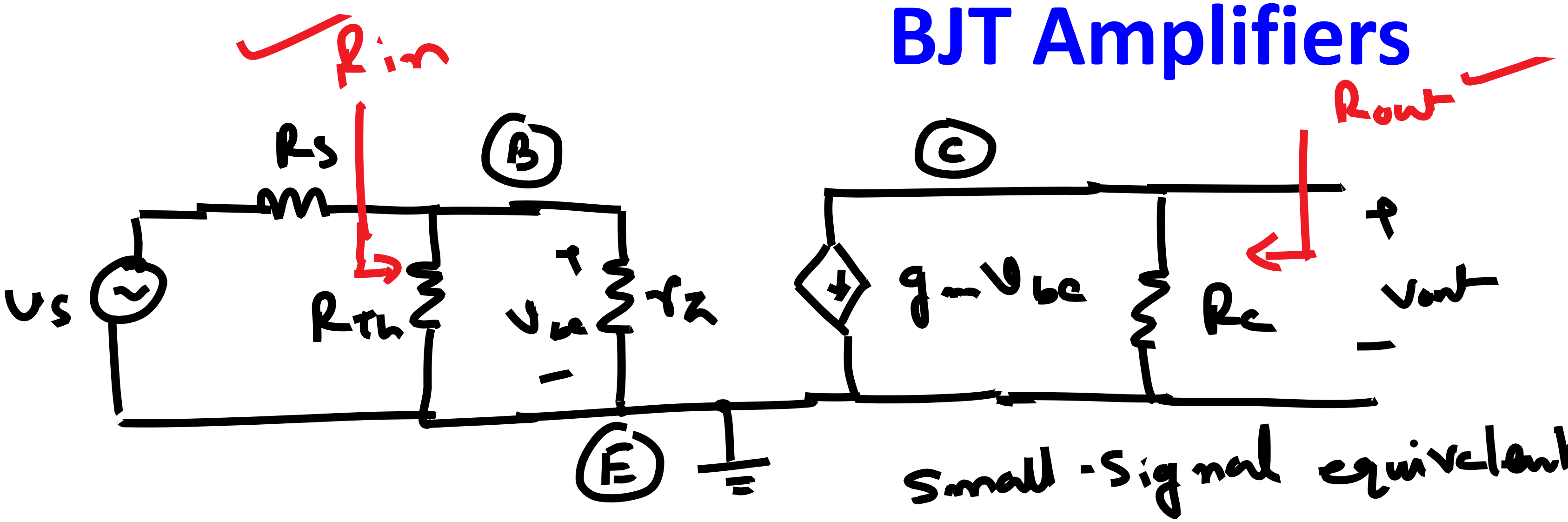


$$R_{Th} = (R_1 \parallel R_2)$$



Small-Signal equivalent ckt.

BJT Amplifiers



Small-signal equivalent ckt.

$$R_{in} = (R_{Th} \parallel r_\pi)$$

$$R_{out} = R_C$$

$$R_{in} = (R_1 \parallel R_2 \parallel r_\pi)$$

$$\text{gain} = \frac{v_{out}}{v_s} \quad ; \quad v_{out} = -g_m v_{be} \cdot R_C$$

$$v_{be} = v_s \times \frac{R_{Th} \parallel r_\pi}{R_s + R_{Th} \parallel r_\pi}$$

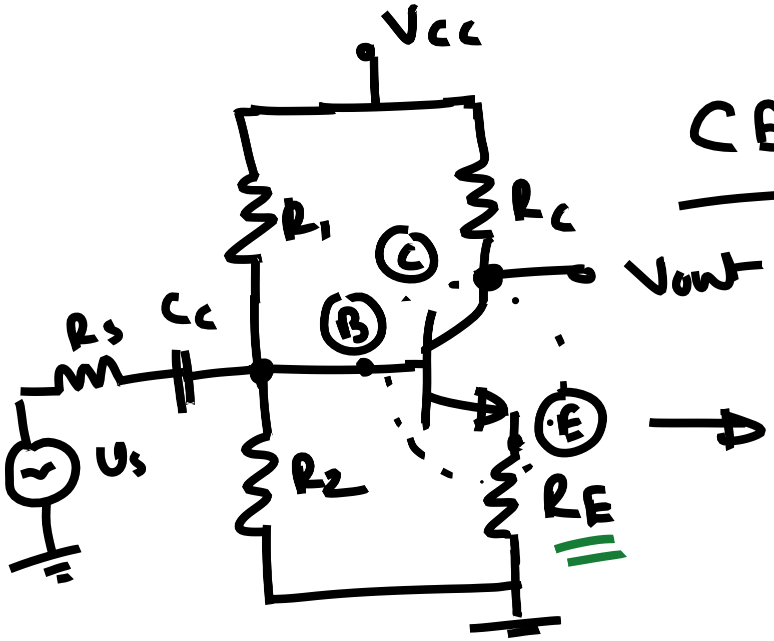
$$\text{gain} = \frac{v_{out}}{v_{in}} = \frac{-g_m v_{be} R_C}{v_s} = -g_m \cdot \frac{\cancel{v_s}}{\cancel{v_s}} \cdot \frac{R_{Th} \parallel r_\pi}{R_s + R_{Th} \parallel r_\pi} \cdot R_C$$

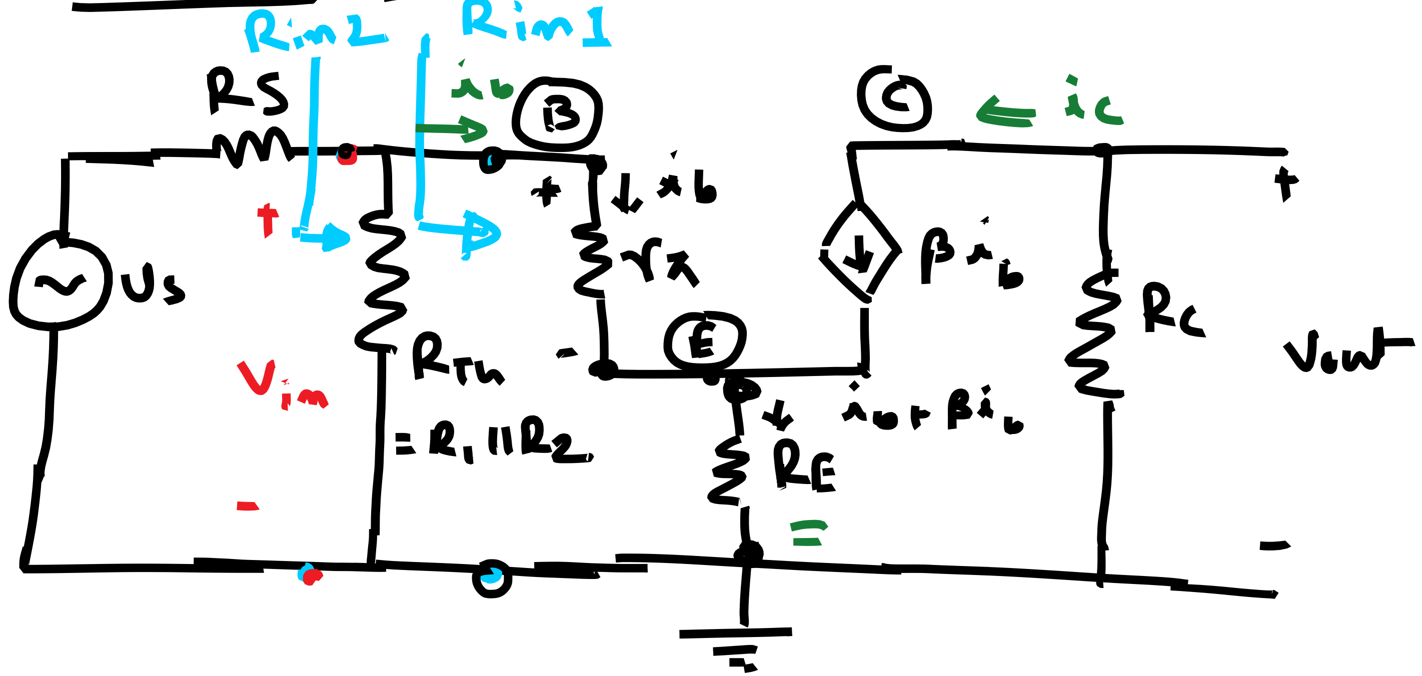
$$R_{Th} = R_1 \parallel R_2$$

$$\text{gain} = -g_m R_C \cdot \frac{R_1 \parallel R_2 \parallel r_\pi}{R_s + R_1 \parallel R_2 \parallel r_\pi}$$

BJT Amplifiers

CE amp. with Emitter Resistan. → ??



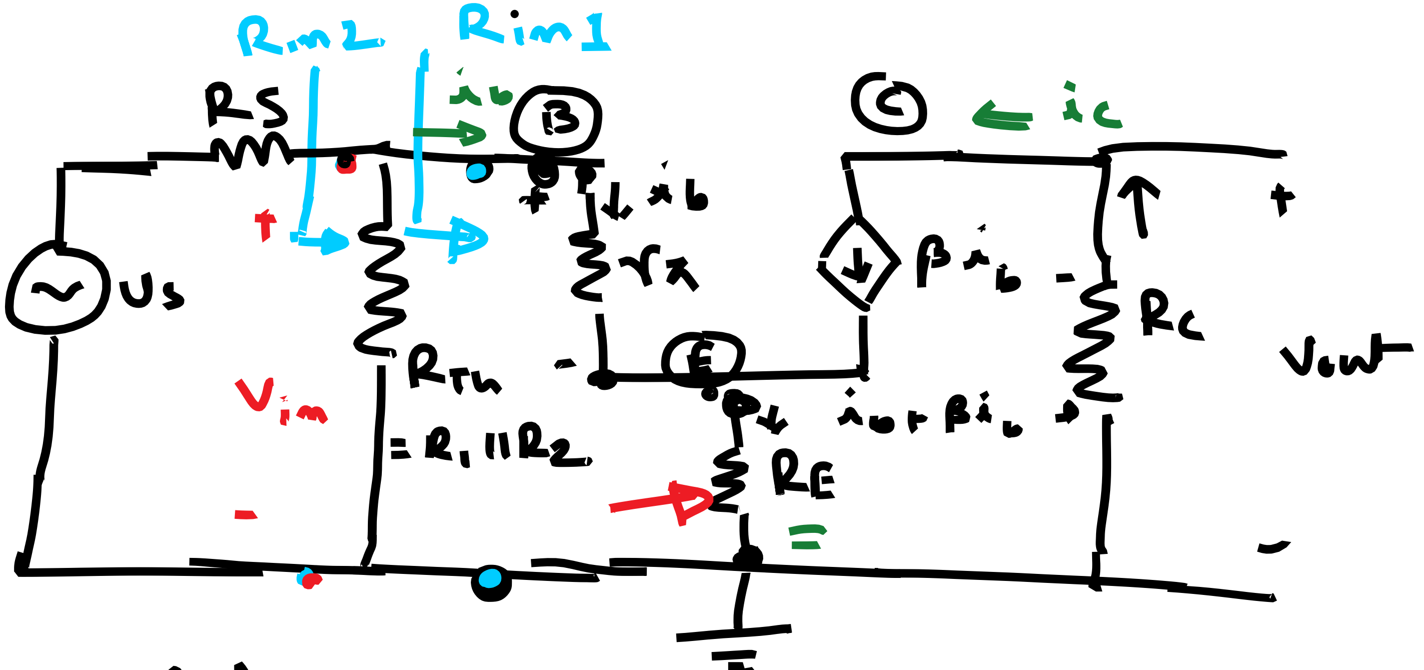


$$V_{in} = i_b r_\pi + R_E(i_b + \beta i_b) = i_b[r_\pi + (1+\beta)R_E]$$

$$R_{in_1} = \frac{V_{in}}{i_b} = r_\pi + \underline{(1+\beta)R_E}$$

$$R_{in2} = R_1 \| R_2 \| R_{in1}$$

BJT Amplifiers



$$\frac{V_{in}}{V_s} = \frac{R_{in2}}{R_{in2} + R_s}$$

$$\Rightarrow V_{in} = V_s \times \frac{R_{in2}}{R_{in2} + R_s}$$

$$V_{out} = -\beta i_b \cdot R_c$$

$$gain = \frac{V_{out}}{V_s} = -\beta R_c \times \frac{V_{in}}{R_{in1}} \times \frac{1}{V_s} = -\frac{\beta R_c}{r_\pi + (1+\beta) R_E} \left(\frac{V_{in}}{V_s}\right)$$

$$= -\frac{\beta R_c}{r_\pi + (1+\beta) R_E} \times \frac{R_{in2}}{R_{in2} + R_s}$$

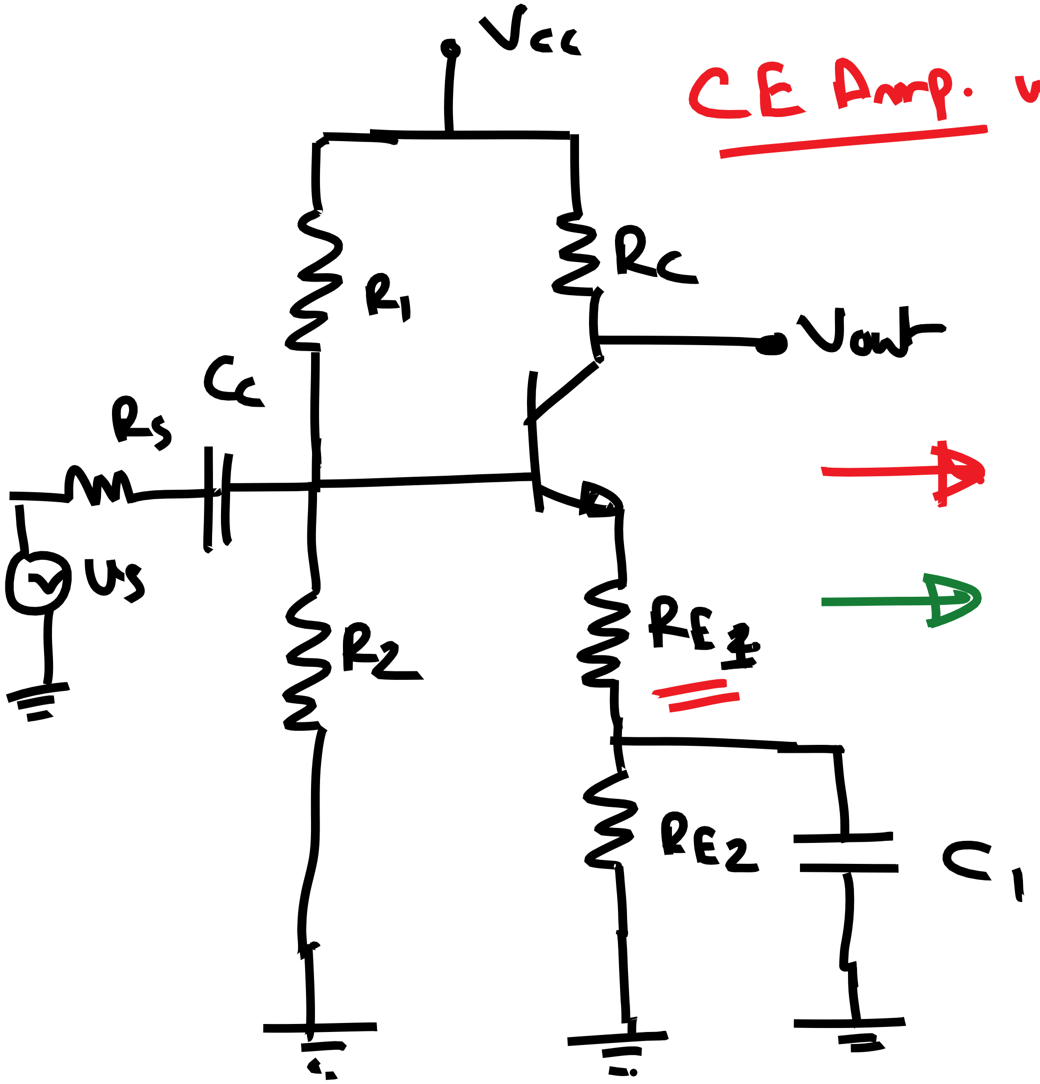
; if, $R_E(1+\beta) >> r_\pi$ and $R_{in2} >> R_s$

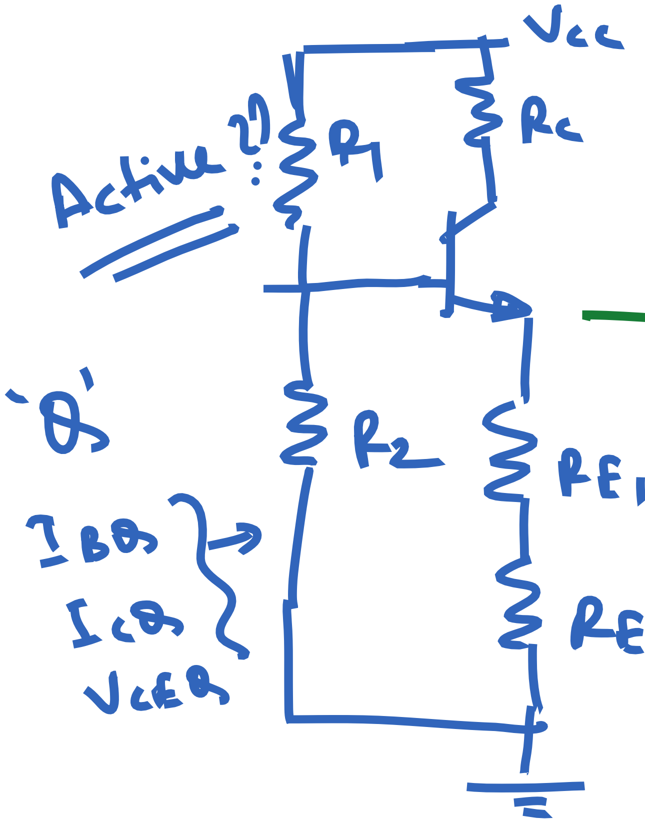
$$\underline{\underline{gain}} = -\frac{\beta R_c}{(1+\beta) R_E} \approx -\left(\frac{R_c}{R_E}\right)$$

Q-Point Stable, independent of 'β'

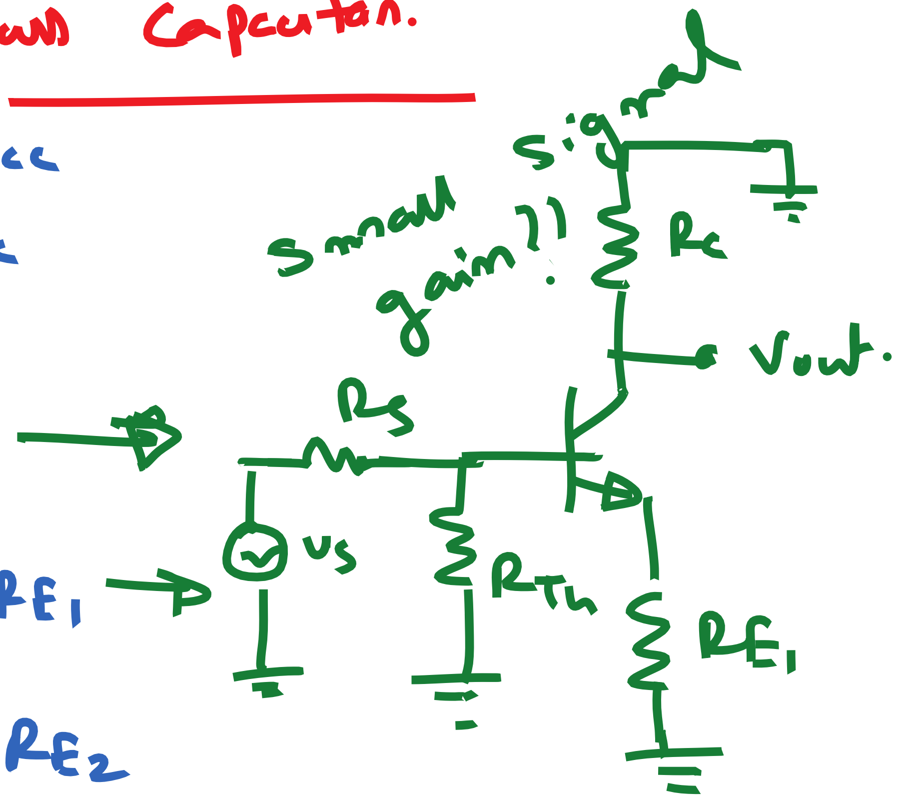
BJT Amplifiers

CE Amp. with Emitter Bypass Capacitor:





DC equv. ckt.



AC equv ckt.

gain: ??